

SENSOR REQUIREMENTS FOR EARTH
AND PLANETARY OBSERVATIONS

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ABSTRACT

Future generations of Earth and planetary remote sensing instruments will require extensive developments of new long-wave and very long-wave infrared detectors. The upcoming NASA Earth Observing System (EOS) will carry a suite of instruments to monitor a wide range of atmospheric and surface parameters with an unprecedented degree of accuracy for a period of 10 to 15 years. These instruments will observe Earth over a wide spectral range extending from the visible to nearly 17 micrometers with a moderate to high spectral and spacial resolution. In addition to expected improvements in communication bandwidth and both ground and on-board computing power, these new sensor systems will need large two-dimensional detector arrays. Such arrays exist for visible wavelengths and, to a lesser extent, for short wavelength infrared systems. The most dramatic need is for new LWIR and VLWIR detector technologies that are compatible with area array readout devices and can operate in the temperature range supported by long life, low power refrigerators. A scientific need for radiometric and calibration accuracies approaching 1% translates into a requirement for detectors with excellent linearity, stability and insensitivity to operating conditions and space radiation. Current examples of the kind of scientific missions these new thermal IR detectors would enhance in the future include instruments for Earth science such as AIRS, MODIS, SAFIRE and OVO. Planetary exploration missions such as Cassini also provide examples of instrument concepts that could be enhanced by new IR detector technologies.

SENSOR REQUIREMENTS FOR EARTH AND PLANETARY EXPLORATION

Moustafa T. Chahine

DETECTOR REQUIREMENTS — GENERAL REMARKS

- PERFORMANCE OF PROPOSED INSTRUMENTS DEPENDS ALMOST ENTIRELY ON DETECTOR PERFORMANCE
- INSTRUMENT PERFORMANCE REQUIREMENTS OFTEN DICTATED BY EXISTING DETECTOR PERFORMANCE DATA
 - NASA FUNDING PROCESS ENSURES THAT PROPOSED DETECTOR PERFORMANCE MUST:
 - a, EXIST
 - b, BE READILY AVAILABLE, WITH FLIGHT HERITAGE
 - c, BE BELIEVED TO SATISFY a, AND b, BY THE COMMUNITY
 - PROPOSED INSTRUMENTS REQUIRING DETECTOR DEVELOPMENT PROGRAMS FARE POORLY AGAINST THOSE THAT DO NOT
- FOR THESE REASONS, REAL DETECTOR REQUIREMENTS ARE OFTEN NOT COMMUNICATED TO THOSE ABLE TO ADDRESS THEM
- THE PRIMARY PURPOSE OF THIS MEETING IS TO ACHIEVE THIS COMMUNICATION.

EARTH OBSERVING SYSTEM (EOS) PAYLOAD

Eos-A

AIRS (JPL)	3-15.4 μ m
AMSU	
CERES (LaRC)	0.2-100 μ m
HIRDLS (NCAR/ OXFORD)	6-18 μ m
EOSP	
GGI	
HIMSS/MIMR/AMSR	
HIRIS	
IPEI	
ITIR (JAP)	0.52-11.65 μ m
MISR	
MODIS-N (GSFC)	0.4 - 14.24 μ m
MODIS-T/MERIS	
MOPITT/TRACER	

Eos-B

ALT/RA	
GGI	
GLRS	
IPEI	
LIS	
MLS	
SAFIRE (LaRC)	6.4-125 μ m
SAGE III	
SCANSCAT/STIKSCAT	
SOLSTICE	
SWIRLS (JPL)	7.6-17.2 μ m
TES (JPL)	2.9-17 μ m
XIE	

CRAF PAYLOAD

Acronym	Investigation	PI/Team Leader
ISS	Imaging (Facility)	J. Veverka/Cornell
VIMS 0.35-5.1 μm	Visual/Infrared Mapping Spectrometer (Facility)	T. McCord/U of Hawaii
TIREX >5 μm	Thermal Infrared Radiometer Experiment	F. P.J. Valero/NASA Ames
PEN	Penetrator	W. Boynton/U of Arizona
COMA	Cometary Matter Analyzer	J. Kissel/Max Planck Institut
CIDEX	Comet Ice/Dust Experiment	G. Carle/NASA Ames
SEMPA	Scanning Electron Microscope and Particle Analyzer	A. Albee/CIT
CODEM	Comet Dust Environment Monitor	W.M. Alexander/Baylor Univ
NGIMS	Neutral Gas and Ion Mass Spectrometer	H. Niemann/NASA GSFC
CRIMS	Comet Retarding Ion Mass Spectrometer	T. E. Moore/NASA Marshall
SPICE	Suprathermal Plasma Investigation of Cometary Environments	J. L. Burch/SW Research Inst.
MAG	Magnetometer	B. Tsurutani/JPL
CREWE	Coordinated Radio, Electrons, and Waves Experiment	J. D. Scudder/NASA GSFC
RSS	Radio Science (Facility)	D. K. Yeomans/JPL

CASSINI PAYLOAD

Acronym	Investigation	Wavelength/Freq Range
CIRS (GSFC)	Mid & Far IR Spectrometer	7.5-1000 μm
HSP	High Speed Photometer	117-180 nm
ISS	Solid State Imaging	0.2-1.1 μm
MSAR	Microwave Spectrometer/Radiometer	15-230 GHz
PRWS	Plasma/Radio Wave Spectrometer	5 Hz - 20 MHz
RADR	Radar	14, 30 GHz
RS	Radio Science	3.6-13 cm
UVSI	UV Spectrometer	500-3200 Å
VIMS (JPL)	Visual/Infrared Mapping Spectrometer	0.4-5.2 μm

ATMOSPHERIC INFRARED SOUNDER (AIRS)

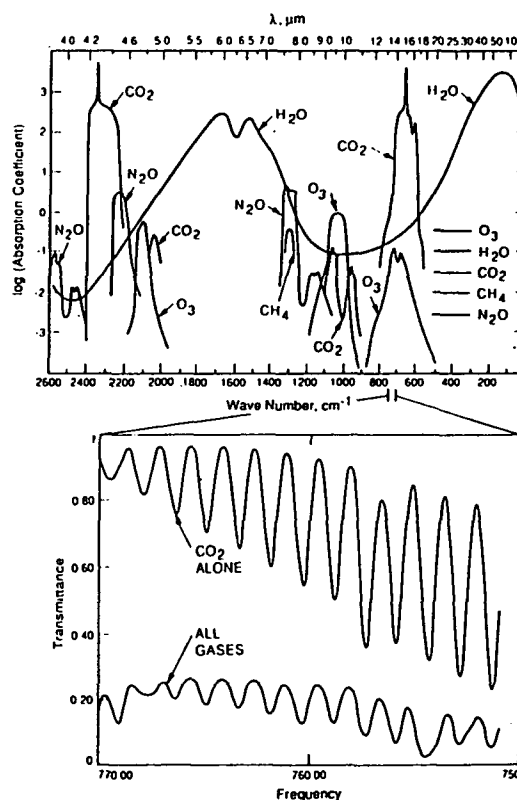
[Team Leader: Moustafa Chahine, JPL]

AIRS

AIRS is a high spectral-resolution sounder covering the range between 3 and 17 μm with more than 4000 spectral measurements, having a resolving power $\Delta\lambda/\lambda = 1/1200$. AIRS permits simultaneous determination of a large number of atmospheric and surface parameters including temperature and humidity profiles, ocean and land surface temperature, clouds, O_3 , CH_4 , and other minor gases. This is accomplished in part through multispectral, narrow bandpass channels which can be selected away from unwanted absorption lines, while taking advantage of the unique spectral properties of several regions such as the high J-lines in the R-branch of the 4.3 μm CO_2 band and the clear super-windows near 3.6 μm .

Atmospheric Infrared Sounder

Infrared Band Absorption of Atmospheric Gases



AIRS (used with AMSU) provides simultaneous determination of a large number of atmospheric and surface parameters under both day and night conditions:

1. Atmospheric temperature profiles with an average accuracy of 1°C and in 1 km thick layers.
2. Relative humidity profiles and total precipitable water vapor
3. Sea surface temperature.
4. Land surface temperature and infrared spectral emissivity.
5. Fractional cloud cover, cloud infrared emissivity, and cloud-top pressure and temperature.
6. Total ozone burden of the atmosphere.
7. Mapping of the distribution of minor atmospheric gases such as methane, carbon monoxide and nitrous oxide.
8. Surface albedo.
9. Snow and ice cover.
10. Outgoing long wave radiation.
11. Precipitation index.

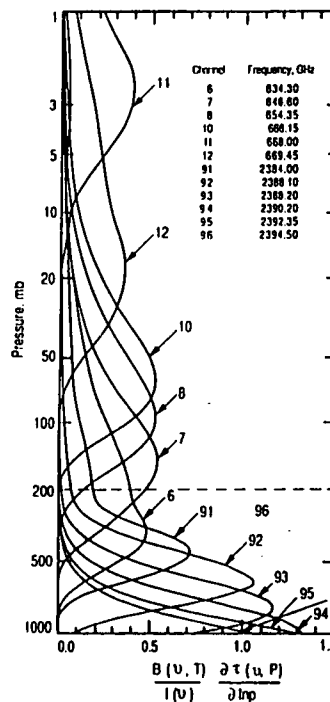
AIRS

Atmospheric Temperature Profile

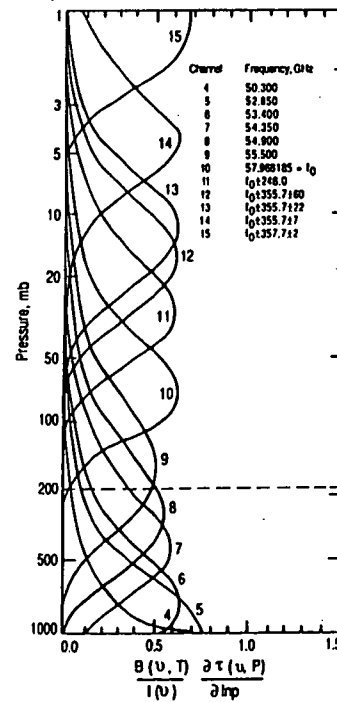
Atmospheric temperature profiles $T(p)$ will be derived with an average accuracy of 1°C in 1 km thick layers. Clear-column temperature profiles will be derived in the presence of multiple cloud layers without requiring any field-of-view (FOV) to be necessarily completely clear. Observations over adjacent FOVs will be used to filter out the effects of clouds on all channels. Improvements in the $T(p)$ are a result of:

- AIRS narrow contribution functions
- Number of available sounding channels
- Minimizing contamination by O_3 , H_2O , ...
- Simultaneous determination of the surface temperature, emissivity and reflectivity
- Use of AMSU lower atmosphere sounding channels to filter out the effects of clouds

AIRS Typical Sounding Channels



AMSU Temperature Sounding Channels



Humidity profiles will be derived from channels selected in the 6.3 μm water vapor band and the 11 μm windows which are sensitive to water vapor continuum. The radiance measured in these channels depends on atmosphere and surface temperature and the distribution of humidity in the atmosphere. The 6.3 μm channels are more sensitive to humidity in the middle and upper troposphere, while the narrow bandpass channels in the 11 μm continuum are more sensitive to humidity in the lower troposphere. Determination of surface temperature and spectral emissivity is essential for obtaining accurate low level water vapor distribution.

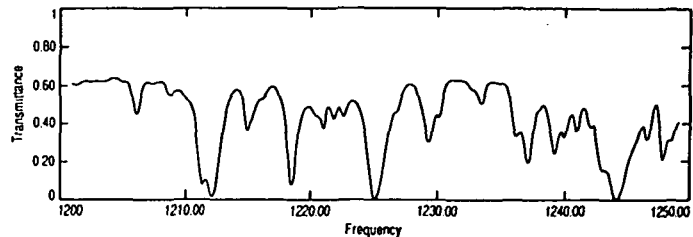
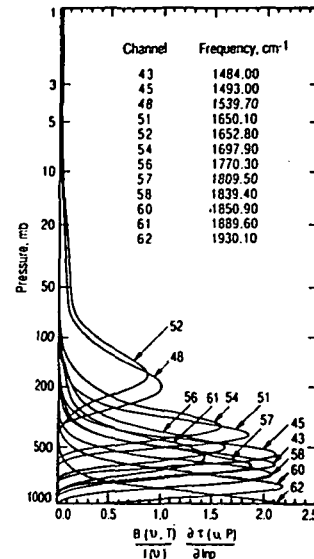


TABLE 1
AIRS FUNCTIONAL PARAMETERS

Design Altitude	705 km
IFOV	1.1°
Cross-track Scan Motion	$\pm 48.95^\circ$
Infrared	
Spectral Coverage	3.4 - 17.0 μm
Spectral Resolution	1200
NE Δ T	0.2 K
Channels	115 (minimum) 3638 Spectral elements
Visible Light	
Spectral coverage	0.4 - 1.1 μm
Channel wavelengths (tentative)	0.40 - 0.50 μm 0.67 - 0.71 μm 0.70 - 0.80 μm 0.9 - 1.0 μm 0.4 - 1.0 μm
Sensitivity	SNR = 100 at albedo = 0.4 (daytime only)
Data Encoding	12 bits/sample
Number of Samples/Cross-track Scan	89
Mean Data Rate	1.8 Mb/s
Maximum Data Rate	1.8 Mb/s

TABLE 2
OPTICAL SYSTEM PARAMETERS

IFOV	± 0.52 °	
Visible/near IR system:		
Fore optics:	full aperture	subapertures
Aperture (mm)	10.0	2.0 (5)
EFL (mm)	50	50
Focal Ratio	F/5	F/25
Relay:		
Magnification	4:1	
Final Focal Ratio	F/13.7	
Detector Diam. (mm)	0.5	
IR systems:		
Fore optics:	full aperture	subapertures
Aperture (mm)	121.0 x 5.5	5.5 x 5.5 (8)
EFL (mm)	500	500
Focal Ratio	F/4.1 x F/90.9	F/90.9
Spectrometers:		
	Short-Wave	Long-Wave
Aperture (mm)	69.3 x 138.6	69.3 x 138.6
Grating Incidence Angle	60 °	60 °
Grating Diffraction Angle	0 °	0 °
Grating Spacing (mm)	0.057	0.127
EFL (mm)	138.6	138.6
Focal Ratio	F/2.0 x F/1.0	F/2.0 x F/1.0
Pixel size (mm)	0.2 x 0.1	0.2 x 0.1

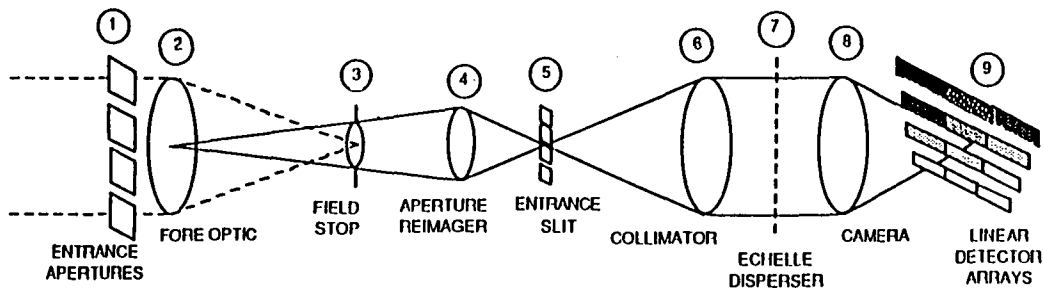
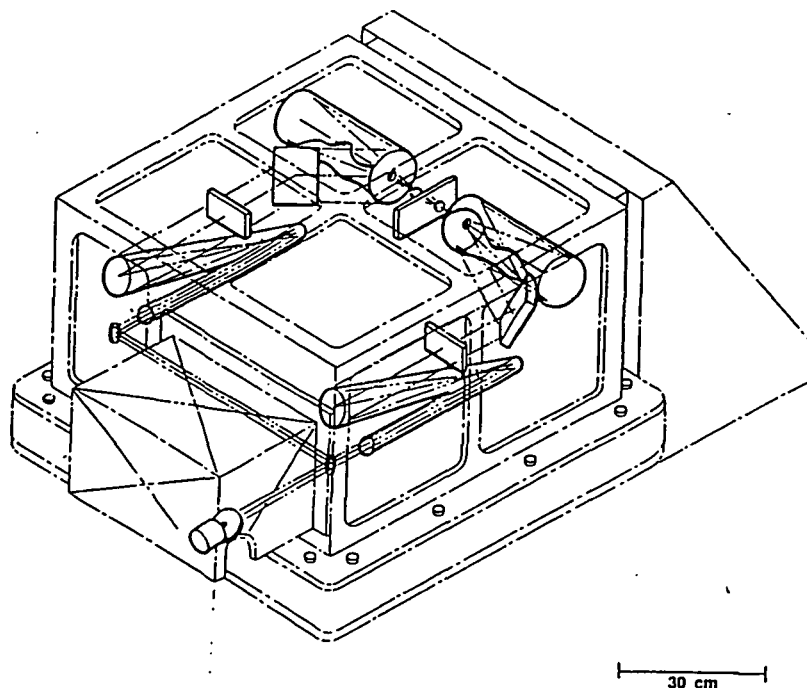


Figure 2
SCHEMATIC MULTI-APERTURE SPECTROMETER DIAGRAM

In the multi-aperture spectrometer, several sub-apertures (1) in a line across the telescope aperture are relayed to the spectrometer slit (5), then dispersed (7) and re-imaged onto a series of linear arrays (9).



AIRS INSTRUMENT DIAGRAM WITH X-RAY
VIEW OF THE TWO SPECTROMETERS



AIRS DETECTOR TECHNOLOGY REQUIREMENTS / CHALLENGES

<u>ISSUE</u>	<u>REQUIREMENT</u>	<u>CHALLENGE</u>
Photon Flux Range	$10^7 - 10^{12}$ photons/sec/pix	Large dynamic range, low readout noise, storage and speed
Radiometric Performance	BLIP at all flux levels, 1% linearity and calibration accuracy	Low noise detectors, high QE, feedback in cell, radiation tolerance
Wavelength Range	To $15.4 \mu\text{m}$ extendable to $17 \mu\text{m}$	Only single pixels demonstrated in MCT, linear arrays required
Operating Temperature	Compatible with long life coolers, $T \geq 60 \text{ K}$	Not demonstrated, new options needed
Power Dissipation	$10 - 50 \mu\text{W}$ per pixel with readout $0.1 - 0.2 \text{ W}$ for full focal plane	Cooler power limitation

MODERATE RESOLUTION IMAGING SPECTROMETER (MODIS-N)

[Team Leader: Vince Salomonson, GSFC]

MODERATE RESOLUTION IMAGING SPECTROMETER SCIENCE OBJECTIVES

- **STUDIES OF SPATIAL AND TEMPORAL VARIABILITY OF OCEANIC SURFACE PROPERTIES WITH SPECIAL EMPHASIS ON OCEAN PRIMARY PRODUCTIVITY**
- **STUDIES OF THE SPATIAL AND TEMPORAL VARIABILITY IN LAND SURFACE PROPERTIES WITH EMPHASIS ON PROBLEMS SUCH AS DESERTIFICATION, REGIONAL VEGETATION STRESS DUE TO ACID RAIN OR DROUGHT, AND SUCCESSION OR CHANGE IN VEGETATION SPECIES DUE TO DEFORESTATION AND ANTHROPOGENIC EFFECTS**
- **STUDIES OF TROPOSPHERIC DYNAMICS, CLIMATOLOGY AND CHEMISTRY AS OBTAINED THROUGH OBSERVATIONS OF CLOUD CHARACTERISTICS, AEROSOLS, WATER VAPOR, AND TEMPERATURE (INCLUDING SURFACE TEMPERATURE)**

MODERATE RESOLUTION IMAGING SPECTROMETER INSTRUMENT DESCRIPTION

- SCANNING IMAGING SPECTROMETER
- PIXEL SIZES OF 214 M, 428 M, AND 856 M
- SWATH WIDTH OF 2300 KM
- SPECTRAL RANGE 0.6-15 MICRONS, 36 BANDS
- 200 KG, 8.3 MBPS, 250 W

MODIS-N SPECTRAL CHANNEL CHARACTERISTICS

No. CHANNELS	λ (μm)	$\Delta\lambda$ (nm)	IFOV (meters)	S/N (AT 70° SZA)	NEDT (TYPICAL)	COMMENTS
2	0.6 - 0.9	40 - 50	214	100 - 200		EDGE DETECTION
5	0.4 - 2.1	20 - 50	428	100 - 300		LAND PROCESSES AND CLOUD CHARACTERISTICS
7	0.4 - 0.9	10 - 15	856	500 - 900		OCEAN COLOR
2	0.6 - 0.7	10 - 15	856	1100		FLUORESCENCE
3	0.9 - 1.0	10 - 50	856	60-250		WATER VAPOR
10	3.7 - 8.6	50 - 300	856		0.05K AT 300K	ATMOS. PARAMETERS AND SURFACE TEMPERATURE
7	9.7 - 14.2	300 - 500	856		0.25K AT 250K	CLOUD AND SURFACE TEMPERATURE
36						

MODIS-N INSTRUMENT SUMMARY

PARAMETERS	DESIGN SPECIFICATIONS OR EXPECTED PERFORMANCE
PLATFORM ALTITUDE	705 km
IFOV (No. OF BANDS AT IFOV)	29 AT 1.21 mrad (856 m) 5 AT 0.607 mrad (428 m) 2 AT 0.303 mrad (214 m)
SWATH	110 deg/2330 km
SPECTRAL BANDS	36 BANDS TOTAL (19/0.4-3.0 μ m; 17/3-15 μ m)
RADIOMETRIC ACCURACY	5% ABSOLUTE, < 3 μ m 1% ABSOLUTE, > 3 μ m 2% REFLECTANCE
QUANTIZATION	12 bit
POLARIZATION SENSITIVITY	2% MAX, < 2.2 μ m
MODULATION TRANSFER FUNCTION	0.3 AT NYQUIST
S/N PERFORMANCE	830:1 (443 nm) 745:1 (520 nm) 503:1 (865 nm)
(70 degree SOLAR ZENITH/OCEANS)	
NEDT PERFORMANCE (THERMAL BANDS)	LESS THAN 0.05
AT 300 deg K/WINDOW BANDS	
SCAN EFFICIENCY	(TO BE DETERMINED)
INTEGRATION TIME	(TO BE DETERMINED)
SIZE (APPROX)	1 x 1.6 x 1 m
WEIGHT	APPROX 200 kg
POWER	250 W
PEAK DATA RATE	15 MB/S (DAYTIME)
DUTY CYCLE	100%

MODIS-N LWIR PARAMETERS

BAND NUMBER	CENTER WVLNGTH (μ m)	DELTA WVLNGTH (nm)	TYP. SCENE TEMP (K)	TYP. SPECTRAL RADIANCE ($^{\circ}$)	NEDT (K)	NOISE EQUIV. SPECTRAL RADIANCE ($^{\circ}$)	REQ. SIGNAL/NOISE RATIO	NOMINAL NEP (W)**	CALCULATED D*
30	9.73	300	250	3.69	0.25	2.19E-02	168	6.04E-11	4.39E+10
31	11.03	500	300	9.55	0.05	7.01E-03	1362	3.22E-11	8.22E+10
32	12.02	500	300	8.94	0.05	6.06E-03	1475	2.79E-11	9.51E+10
33	13.34	300	260	4.52	0.25	1.83E-02	247	5.05E-11	5.25E+10
34	13.64	300	250	3.76	0.25	1.61E-02	234	4.44E-11	5.97E+10
35	13.94	300	240	3.11	0.25	1.41E-02	221	3.89E-11	6.81E+10
36	14.24	300	220	2.08	0.35	1.54E-02	135	4.25E-11	6.24E+10

NOTE:

THE COLUMNS UP TO REQUIRED SIGNAL-TO-NOISE RATIO ARE SPECIFICATION VALUES FROM THE SEPT. 19, 1989 SPECIFICATION CIRCULATED TO INDUSTRY FOR REVIEW. THE CALCULATED D* VALUES DEPEND ON SYSTEM ASSUMPTIONS AND MUST BE ACHIEVED AT FOCAL PLANE TEMPERATURES WARMER THAN 85K.

SYSTEM ASSUMPTIONS ANTICIPATE THE USE OF SHORT LINEAR WHISKBROOM ARRAYS OF LESS THAN 20 DETECTORS.

* WATTS/(cm²-sr- μ m)

** ASSUME:

APERTURE (cm)	20
F-NUMBER -	2.00
TRANSMISSION	0.20
IFOV -	1.21E-03
DET. SIZE (μ m) -	4.84E+02
NOISE BW (Hz) -	3000

TROPOSPHERIC EMISSION SPECTROMETER (TES)

[P.I.: Reinhard Beer, JPL]

TROPOSPHERIC EMISSION SPECTROMETER SCIENCE OBJECTIVES

- GENERATE VERTICAL CONCENTRATION PROFILES ON A GLOBAL BASIS OF THE FOLLOWING SPECIES WITH SUB-SCALE-HEIGHT RESOLUTION AND 5° LATITUDE SPACING:

<u>Misc.</u>	<u>HO_x</u>	<u>NO_y</u>	<u>Hydrocarbons</u>	<u>SO_x</u>	<u>CFCs</u>
O ₃	H ₂ O	NO	CH ₄	SO ₂	CF ₃ Cl
CO	H ₂ O ₂	NO ₂	C ₂ H ₆	COS	CF ₂ Cl ₂
(CO ₂)		HNO ₃	C ₂ H ₂		
N ₂ O		NH ₃			

TES: SPECIES DETECTABILITY MATRIX

		SPECIES																	
									H								C	C	H
		C	H		C		N		N	N	F	F	H	N	S	C	2	2	2
		O	2	O	H	C	2	N	O	O	1	1	C	H	O	O	H	H	O
		2	O	3	4	O	O	O	2	3	1	2	1	3	2	S	6	2	2
LOWER STRATOSPHERE (15 - 30 km)																			
FREE TROPOSPHERE (2 - 15 km)																			
BOUNDARY LAYER (0 - 2 km)																			

MEASURABILITY KEY:



ACCURACY 1 - 10 %



FACTOR OF 2
OR BETTER



TBD



UNLIKELY TO BE
MEASURABLE

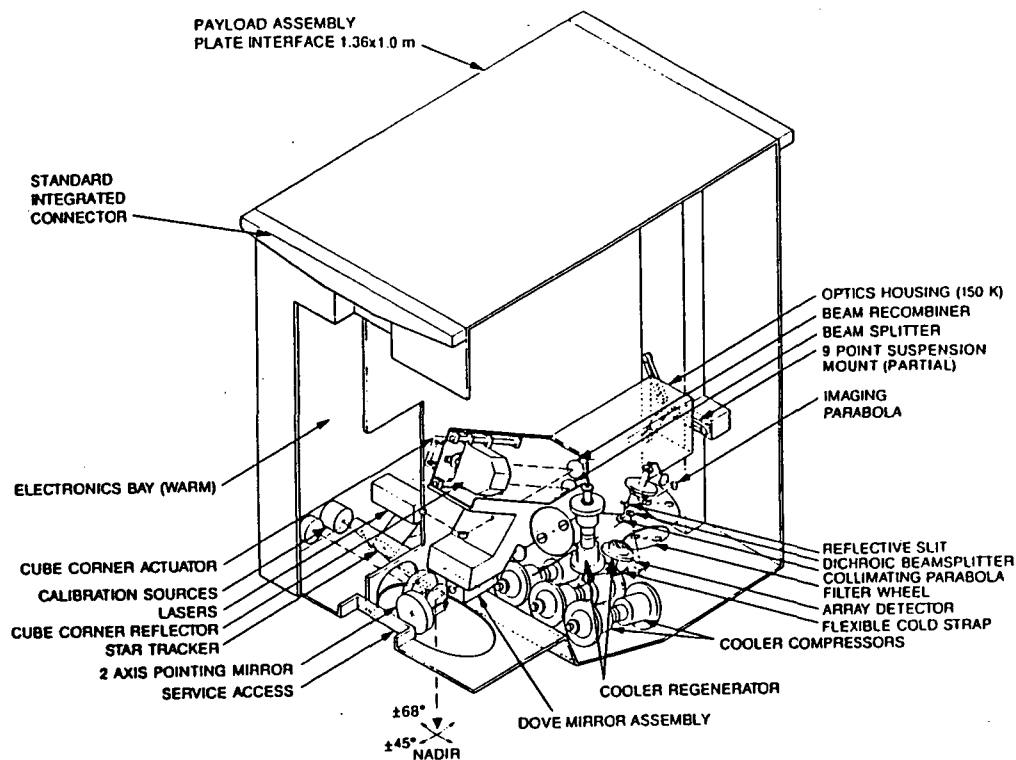


VALUE ASSUMED FOR
TEMPERATURE SOUNDING

TROPOSPHERIC EMISSION SPECTROMETER INSTRUMENT DESCRIPTION

- HIGH SPECTRAL RESOLUTION INFRARED IMAGING FOURIER TRANSFORM SPECTROMETER
- 491 KG, 660 W PEAK POWER
- SPECTRAL COVERAGE 600 TO 3200 CM⁻¹ (2.9 TO 16.6 MICRONS)
- FOUR LINEAR ARRAYS OF 32 DETECTORS, EACH WITH ITS OWN SIGNAL CHAIN, IN CONJUGATE FOCAL PLANES
- ALL DETECTOR ELEMENTS ARE 0.1 MM BY 1.0 MM
- DETECTOR FOV 0.75 X 7.5 MRAD. NADIR PIXEL SUBTENDS 0.5 X 5 KM
- ON-BOARD SOURCES ARE PROVIDED FOR RADIOMETRIC CALIBRATION AND DETECTOR ALIGNMENT

TROPOSPHERIC EMISSION SPECTROMETER CONCEPTUAL DESIGN



TROPOSPHERIC EMISSION SPECTROMETER FOCAL PLANE ARRAY - TECHNICAL SPECIFICATIONS

MATERIAL:	InSb (PV)	HgCdTe (PV)	HgCdTe (PV)	HgCdTe (PC)
WAVEBAND (μm)	2.9-5.6	8.3-12.5	5.3-9.1	11.1-16.7
CUT-OFF FREQ (cm^{-1})	1800-3400	800-1200	1100-1900	600-900
QUANTUM EFFICIENCY	0.6	0.6	0.6	0.8
IMPEDANCE (OHMS)	100 M	10 K	100 K	100
BKGRD FLUX DENSITY	2.9E11-	1.3E14-	8.9E12-	1.2E15-
($\text{Ps}^{-1}\text{cm}^{-1}$)	2.6E14	3.0E15	1.1E15	3.9E15
D* ($\text{cm Hz}^{1/2} \text{W}^{-1}$)	>7.0E11	>5.0E11	>6.0E11	>2.0E11
ELECTRICAL				
BANDWIDTH (kHz)	27	12	14	8.5
OPERATING TEMP (K)	65	65	65	65

**THESE DETECTOR REQUIREMENTS ARE COMPATIBLE
WITH DETECTOR MATERIAL CURRENTLY BEING PRODUCED**

TROPOSPHERIC EMISSION SPECTROMETER PERFORMANCE ESTIMATES

FREQ. RANGE cm^{-1}	WAVELENGTH microns	NADIR SNR (2 sec scan)	LIMB SNR (8 sec scan)
600 - 900	11.1 - 16.7	500 - 600	200 - 300
800 - 1200	8.3 - 12.5	400 - 500	100 - 200
1100 - 1900	5.3 - 9.1	100 - 600	40 - 300
1800 - 3450(N)	2.9 - 5.6	30 - 150	na
1800 - 2450(L)	4.1 - 5.6	na	20 - 40

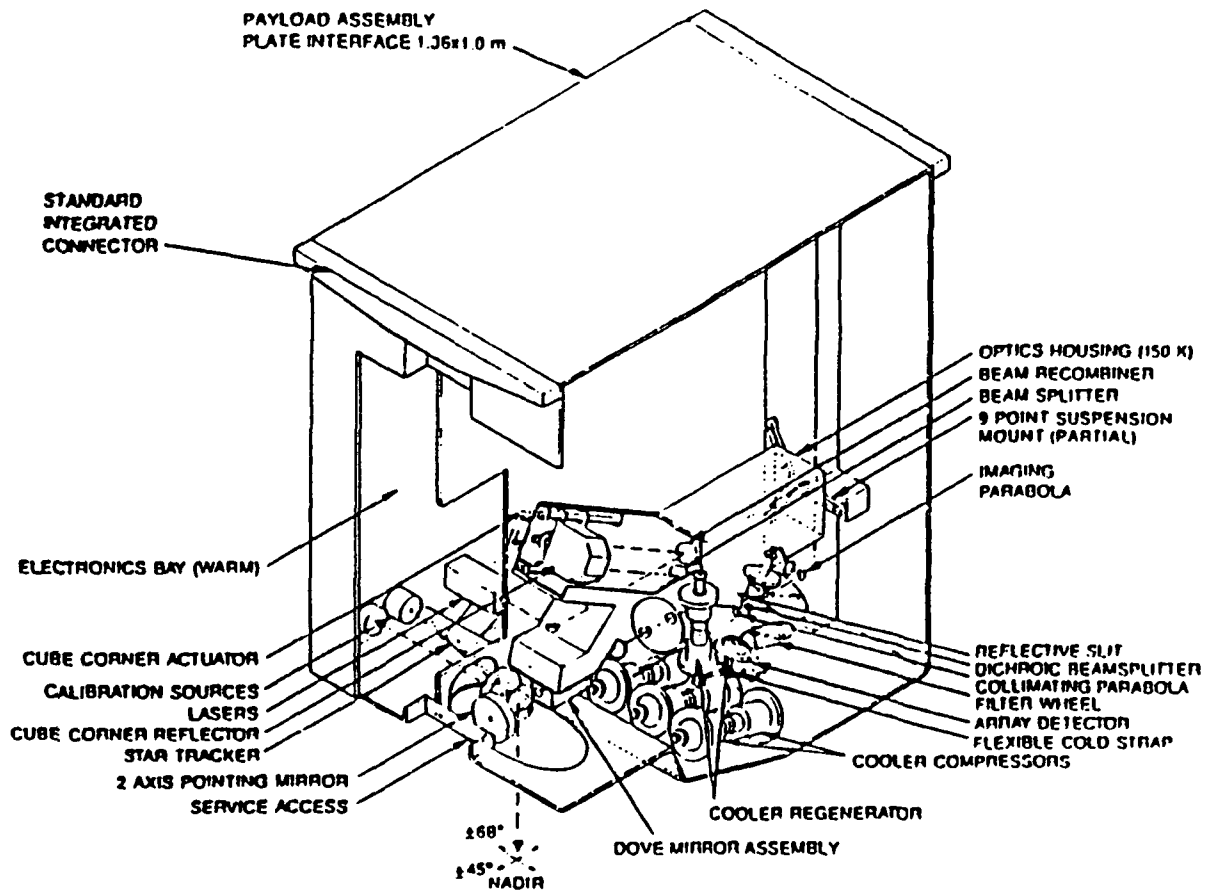
SPECTROSCOPY OF THE ATMOSPHERE USING FAR INFRARED EMISSION (SAFIRE)

[P.I.: Jim Russell, LaRC]

- **SCIENTIFIC GOAL**
 - To improve understanding of the middle atmosphere ozone distribution by conducting and analyzing global-scale measurements of important chemical, radiative, and dynamical processes, including coupling among processes and atmospheric regions.

- **SCIENTIFIC OBJECTIVES**
 - Study key processes in the O_y, HO_y, NO_y, ClO_y, and BrO_y chemical families
 - Study polar night chemistry
 - Conduct non-LTE investigations
 - Investigate diurnal change processes (OH, HO₂, NO₂, N₂O₅, O₃)
 - Conduct dynamics studies and study coupling between chemistry and dynamics
 - Investigate lower stratosphere phenomena (e.g. polar night O₃ depletion)

TROPOSPHERIC EMISSION SPECTROMETER CONCEPTUAL DESIGN



TROPOSPHERIC EMISSION SPECTROMETER FOCAL PLANE ARRAY - TECHNICAL SPECIFICATIONS

MATERIAL:	InSb (PV)	HgCdTe (PV)	HgCdTe (PV)	HgCdTe (PC)
WAVEBAND (μm)	2.9-5.6	8.3-12.5	5.3-9.1	11.1-16.7
CUT-OFF FREQ (cm^{-1})	1800-3400	800-1200	1100-1900	600-900
QUANTUM EFFICIENCY	0.6	0.6	0.6	0.8
IMPEDANCE (OHMS)	100 M	10 K	100 K	100
BKGRD FLUX DENSITY	2.9E11-	1.3E14-	8.9E12-	1.2E15-
($\text{Ps}^{-1}\text{cm}^{-1}$)	2.6E14	3.0E15	1.1E15	3.9E15
D* ($\text{cm Hz}^{1/2} \text{W}^{-1}$)	>7.0E11	>5.0E11	>6.0E11	>2.0E11
ELECTRICAL				
BANDWIDTH (kHz)	27	12	14	8.5
OPERATING TEMP (K)	65	65	65	65

THESE DETECTOR REQUIREMENTS ARE COMPATIBLE
WITH DETECTOR MATERIAL CURRENTLY BEING PRODUCED

TROPOSPHERIC EMISSION SPECTROMETER PERFORMANCE ESTIMATES

FREQ. RANGE cm^{-1}	WAVELENGTH microns	NADIR SNR (2 sec scan)	LIMB SNR (8 sec scan)
600 - 900	11.1 - 16.7	500 - 600	200 - 300
800 - 1200	8.3 - 12.5	400 - 500	100 - 200
1100 - 1900	5.3 - 9.1	100 - 600	40 - 300
1800 - 3450(N)	2.9 - 5.6	30 - 150	na
1800 - 2450(L)	4.1 - 5.6	na	20 - 40

ORBITAL VOLCANOLOGICAL OBSERVATIONS (OVO)

[P.I.: Dave Pieri, JPL]

ORBITAL VOLCANOLOGICAL OBSERVATIONS SCIENCE GOALS

- **IMPROVED UNDERSTANDING OF ERUPTION MECHANISMS**
- **IMPROVED DETERMINATION OF THE NATURE AND AMOUNT OF VOLCANIC CONTRIBUTIONS TO THE GLOBAL ENVIRONMENT**
- **IMPROVED UNDERSTANDING OF HOW THE PRODUCTS OF VOLCANIC ERUPTIONS INTERACT WITH THE ENVIRONMENT TO PRODUCE SIGNIFICANT GLOBAL CHANGES**

ORBITAL VOLCANOLOGICAL OBSERVATIONS MEASUREMENT OBJECTIVES

- **MULTISPECTRAL THERMAL IR MAPPING OF VOLCANIC LITHOLOGIES**
- **BRIGHTNESS TEMPERATURE AND HEAT SOURCE DISTRIBUTION MAPS OF ACTIVE VOLCANIC FEATURES (E.G. LAVA FLOWS, SUMMIT CRATERS, LAVA TUBE SYSTEMS, FUMARoles, HOT WATER LAKES, HOT WATER OCEANIC PLUMES)**
- **BRIGHTNESS TEMPERATURE MAPS OF ERUPTION COLUMNS AND DISPERSED VOLCANIC PLUMES**
- **MULTISPECTRAL DETECTION AND MAPPING OF AIRBORNE ASH PLUMES IN THE PRESENCE OF METEOROLOGICAL CLOUDS**
- **DETERMINATION OF COMPOSITION AND VOLUME OF SUBAERIAL GLOBAL VOLCANIC GAS BUDGET OVER TIME**

ORBITAL VOLCANOLOGICAL OBSERVATIONS DATA PRODUCTS

- **THERMAL MAPS OF SOLID PRODUCTS OF VOLCANIC ERUPTIONS ON THE GROUND**
- **MULTISPECTRAL MAPPING IMAGES OF THE SURFACE OF VOLCANOES**
- **2-D THERMAL MAPS OF AIRBORNE PLUMES**
- **3-D THERMAL PROFILES OF ERUPTION PLUMES**

ORBITAL VOLCANOLOGICAL OBSERVATIONS INFRARED DETECTOR REQUIREMENTS

- **1.0-2.5 μm , 5-10 CHANNELS FOR HIGH TEMPERATURE THERMAL RADIOMETRY, GAS AND AEROSOL MEASUREMENTS**
- **2.5-5.0 μm , 5 CHANNELS FOR LOWER TEMPERATURE RADIOMETRY, GEOLOGICAL MAPPING, GAS AND AEROSOL MEASUREMENTS**
- **8-12 μm , 10+ CHANNELS FOR MULTISPECTRAL MAPPING, LOWEST TEMPERATURE THERMAL RADIOMETRY, ATMOSPHERIC MEASUREMENTS AND CORRECTIONS**
- **IMAGING CAPABILITY REQUIRED, ≥ 25 km SWATH, ≤ 100 m SPATIAL SAMPLING**
- **LOW TEMP RADIOMETRY REQUIRES $\sim 0.3\text{K}$ NedT MEASUREMENT CAPABILITY**
- **MASS CONSIDERATIONS ARGUE FOR DEVELOPMENT OF DETECTORS WITH REDUCED COOLING REQUIREMENTS**

MULTISPECTRAL THERMAL IMAGER (MSTI)

[P.I.: Tim Schofield, JPL]

MULTISPECTRAL THERMAL IMAGER SCIENCE OBJECTIVES AND KEY MEASUREMENTS

- UNDERSTAND THE INTERPLAY BETWEEN RADIATIVE, DYNAMICAL AND PHOTOCHEMICAL PROCESSES IN THE ATMOSPHERES OF SATURN, TITAN AND JUPITER
 - OBTAIN MEASUREMENTS OF THE 3-D DISTRIBUTION OF TEMPERATURE, DYNAMICAL FIELDS, KEY SPECIES CONCENTRATIONS AND AEROSOL EXTINCTION IN THESE ATMOSPHERES WITH COMPREHENSIVE COVERAGE AND RESOLUTION, BOTH SPATIALLY AND TEMPORALLY
- DEVELOP A DESCRIPTION OF THE PHYSICAL AND COMPOSITIONAL UNITS OF THE SATELLITES AND RINGS

OBTAIN COMPREHENSIVE MULTISPECTRAL MEASUREMENTS OF BRIGHTNESS TEMPERATURE AND ALBEDO

MULTI-SPECTRAL THERMAL IMAGER (MSTI) CONCEPTUAL INSTRUMENT SPECIFICATIONS

INSTRUMENT PARAMETER	VALUE/COMMENTS
INSTRUMENT TYPE	MULTI-SPECTRAL THERMAL IMAGER
MEASUREMENT TECHNIQUES	GAS CORRELATION AND FILTER RADIOMETRY
SPECTRAL CHANNELS AND RANGE	8 CHANNELS, 8-14 μm 7 CHANNELS, 15-100 μm 1 CHANNEL, 0.3-3.0 μm
TELESCOPE APERTURE	NARROW ANGLE, 16 cm WIDE ANGLE, 4 cm
NARROW ANGLE FOV	ARRAY, 1.15° x 1.15°
WIDE ANGLE FOV	ARRAY, 4.58° x 4.58°
MID-IR DETECTOR	64 x 64 PV HgCdTe ARRAY, 70K
FAR-IR AND SOLAR DETECTOR	64 x 64 BOLOMETER ARRAY, 180K
DATA RATE	1.5 kbps, APOCHROME 3.0 kbps, FAR ENCOUNTER 6.0 kbps, NEAR ENCOUNTER
INSTRUMENT DATA BUFFER	2 MBytes
SPACECRAFT POINTING PITCH, ROLL, AND YAW	CONTROL, 2 mrad KNOWLEDGE, 1 mrad STABILITY, 100 μrad - 2 seconds STABILITY, 300 μrad - 30 seconds
MASS GOAL	23 kg
POWER GOAL	19 WATTS (AVERAGE)

MULTI-SPECTRAL THERMAL IMAGER (MSTI) CHANNEL SPECTRAL CHARACTERISTICS AND MEASUREMENT FUNCTIONS

CHANNEL (1)	BANDPASS cm ⁻¹	BAND CENTER, μm	CHANNEL TYPE (2)	MEASUREMENT FUNCTION
FILTER WHEEL A - MID INFRARED, 70 K HgCdTe DETECTOR ARRAY, 64 x 64 PIXELS				
A1	1240 - 1290	7.9	0.5 cm CELL, 300 mbar CH ₄] STRATOSPHERIC TEMPERATURE
A2	1240 - 1290	7.9	1.5 cm CELL, 300 mbar CH ₄	
A3	805 - 845	12.1	0.5 cm CELL, 300 mbar C ₂ H ₆] ETHANE CONCENTRATION
A4	805 - 845	12.1	1.5 cm CELL, 300 mbar C ₂ H ₆	
A5	730 - 760	13.4	0.5 cm CELL, 150 mbar C ₂ H ₂] ACETYLENE CONCENTRATION
A6	730 - 760	13.4	1.5 cm CELL, 150 mbar C ₂ H ₂	
A7	920 - 1050	10.2	BANDPASS FILTER	- PHOSPHINE
A8	1120 - 1180	8.7	BANDPASS FILTER	- AMMONIA ICE
FILTER WHEEL B - FAR INFRARED, 180 K BOLOMETRIC DETECTOR ARRAY, 64 x 64 PIXELS				
B1	570 - 630	16.7	BANDPASS FILTER] TROPOSPHERIC TEMPERATURE ORTHO-PARA HYDROGEN RATIO AEROSOL DISTRIBUTION
B2	470 - 510	20.4	BANDPASS FILTER	
B3	350 - 390	27.0	BANDPASS FILTER	
B4	210 - 250	43.5	BANDPASS FILTER	
B5	170 - 210	52.6	BANDPASS FILTER	
B6	80 - 140	90.1	BANDPASS FILTER] ENERGY BALANCE
B7	OPEN	-	OPEN	
B8	3333 - 33333	0.54	LONGWAVE BLOCKER	

(1). IMAGING IS PERFORMED IN ALL SPECTRAL CHANNELS.

(2). CHANNELS A1 - A6 PERFORM GAS CORRELATION RADIOMETRY USING BANDPASS FILTERS AND CELLS CONTAINING THE GAS INDICATED TO OBTAIN HIGH ENERGY GRASP, SPECTRAL DISCRIMINATION, AND SPECIES SELECTIVITY. CHANNELS A7, A8, AND B1 - B8 BANDPASS FILTERS ONLY.

MULTISPECTRAL THERMAL IMAGER (MSTI) LWIR FOCAL PLANE ARRAY REQUIREMENTS

- D^* ($\text{cm} \text{ hz}^{1/2} \text{ w}^{-1}$)**

GOAL: $\geq 2.0\text{E}+11$ ($8\mu\text{m}$), $\geq 2.0\text{E}+10$ ($13.5\mu\text{m}$), $\geq 1.0\text{E}+09$ ($100\mu\text{m}$)
REQ: $\geq 1.0\text{E}+11$ ($8\mu\text{m}$), $\geq 1.0\text{E}+10$ ($13.5\mu\text{m}$), $\geq 1.0\text{E}+10$ ($100\mu\text{m}$)
- CURRENT PV-HgCdTe TECHNOLOGY CAN MEET THE D^* REQUIREMENTS, BUT CANNOT MEET THE GOALS AT BOTH 8 AND 13.5 μm SIMULTANEOUSLY**

COMPOSITE INFRARED SPECTROMETER (CIRS)

[P.I.: Virgil Kunde, GSFC]

COMPOSITE INFRARED SPECTROMETER SCIENCE OBJECTIVES

- **DETERMINE THE TROPOSPHERIC AND STRATOSPHERIC TEMPERATURE AND AEROSOL STRUCTURE OF SATURN AND TITAN**
- **DETERMINE THE MIXING RATIOS AND SPATIAL DISTRIBUTIONS OF TRACE GASES IN BOTH ATMOSPHERES**
 - **MANY ORGANIC MOLECULES FOR TITAN**
 - **PH₃ AND NH₃ FOR SATURN**
- **CONSTRAIN THE PROPERTIES OF NH₃ ICE CLOUDS IN SATURN'S ATMOSPHERE**
- **DETERMINE THE BULK COMPOSITION OF SATURN'S ATMOSPHERE**
- **DETERMINE SURFACE TEMPERATURE PROPERTIES OF THE SMALLER ICY SATELLITES AND THE EMISSIVITY OF THE RINGS**

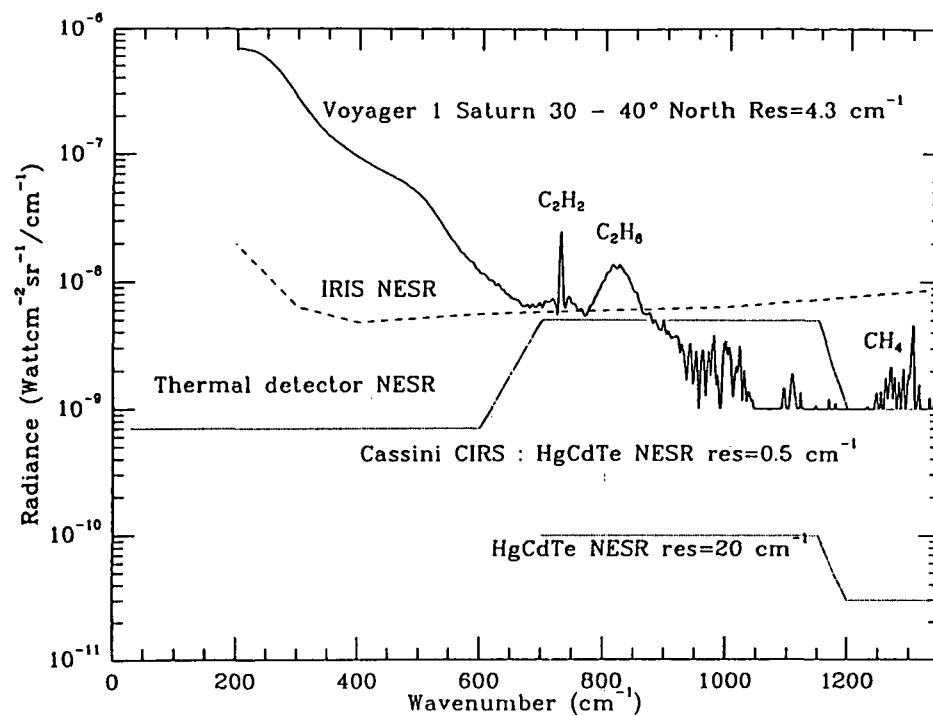


Figure B6 CIRS sensitivity for Saturn.

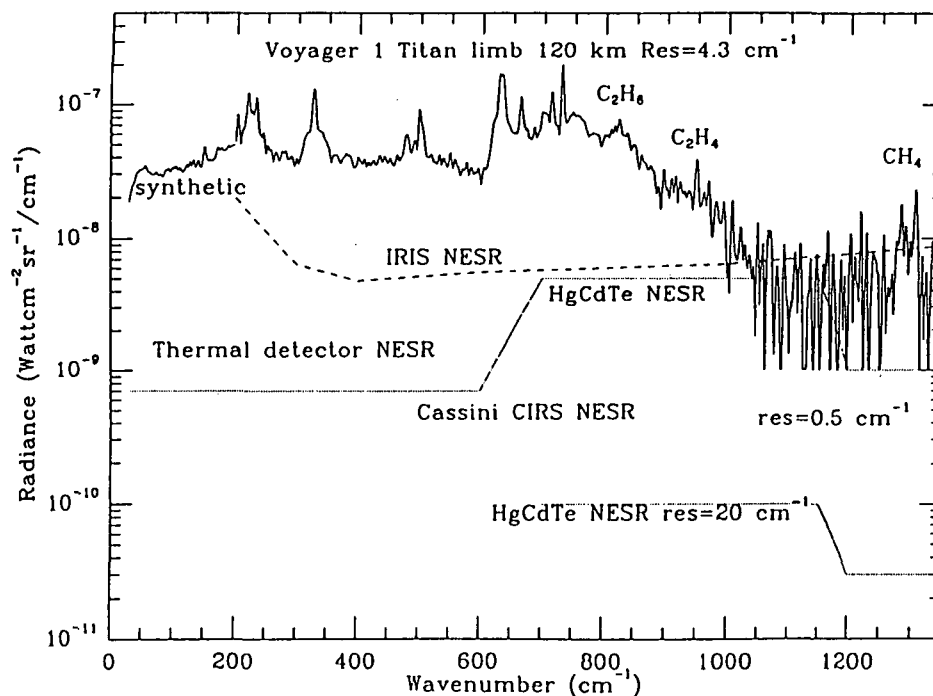


Figure B7 CIRS sensitivity for Titan.

COMPOSITE INFRARED SPECTROMETER INSTRUMENT CHARACTERISTICS

- DUAL INTERFEROMETER CONFIGURATION SHARING A 50 CM CASSEGRAIN TELESCOPE
- SPECTRAL RANGE 7.5-1000 μm
- SPECTRAL RESOLUTION 0.25 cm^{-1} UNAPODIZED
- INDIVIDUAL DETECTOR FIELD-OF-VIEW .25° (FAR-IR), .0057° (MID-IR)
- FAR-IR INTERFEROMETER EMPLOYS A 1x5 ARRAY USING EITHER THERMOPILES OR PYROELECTRICS
- MID-IR INTERFEROMETER EMPLOYS TWO 1 x 43 HgCdTe ARRAYS, COOLED TO 70-90K

POLARIZING FTS (CIRS)

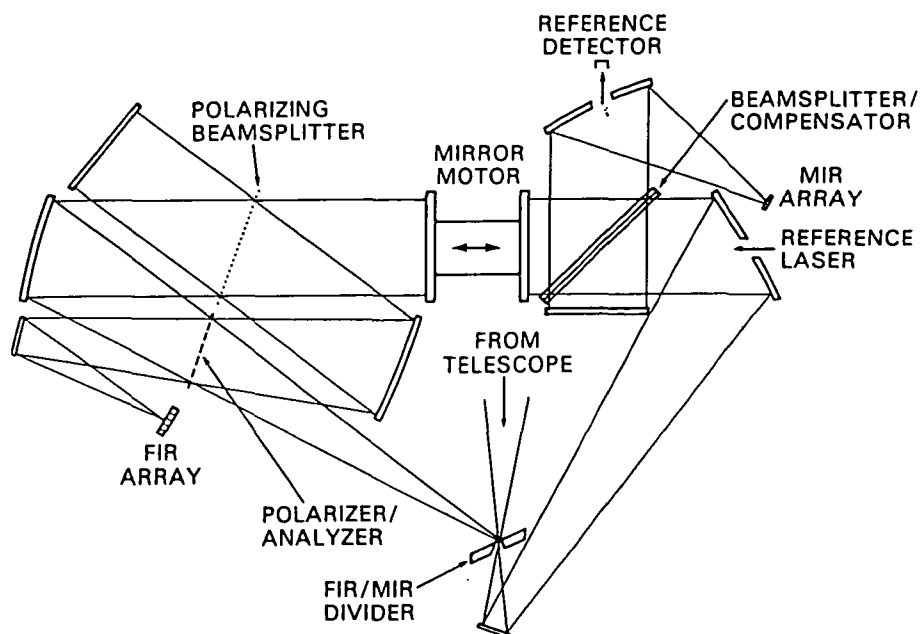


Figure B8 Optical schematic for CIRS.

COMPOSITE INFRARED SPECTROMETER FOCAL PLANE PARAMETERS

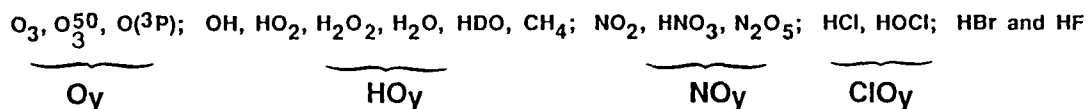
	<u>#1</u>	<u>#2</u>	<u>#3</u>
SPECTRAL RANGE (cm ⁻¹)	10-700	700-1200	1200-1400
DETECTORS	THERMOPILE (1x5)	HgCdTe (1x43)	HgCdTe (1x43)
PIXEL FOV (mrad)	4.3x12.9	0.1x0.3	0.1x0.3
PIXEL AΩ (cm ² -sr)	1.1x10 ⁻¹	6.1x10 ⁻⁵	6.1x10 ⁻⁵
NEP (W Hz ^{-1/2})	2x10 ⁻¹¹	8x10 ⁻¹⁴	2x10 ⁻¹⁴
NESR (W cm ⁻² sr ⁻¹ /cm ⁻¹)	7x10 ⁻¹⁰	5x10 ⁻⁹	1x10 ⁻⁹
TEMPERATURE (K)	170	90	90

GENERAL AREAS FOR EXPERIMENT ENHANCEMENT

- ALL THE PROPOSED EXPERIMENTS WOULD BE ENHANCED BY ONE OR MORE OF THE FOLLOWING IMPROVEMENTS.
 - IMPROVED DETECTOR PERFORMANCE, GIVING:
 - SAME INSTRUMENT PERFORMANCE AT HIGHER DETECTOR TEMPERATURES.
 - IMPROVED PERFORMANCE AT THE SAME DETECTOR TEMPERATURE
 - LOWER INSTRUMENT AND DETECTOR OPERATING TEMPERATURES, GIVING:
 - IMPROVED PERFORMANCE WITH EXISTING DETECTORS
 - IMPROVED DETECTOR PERFORMANCE PLUS LOWER OPERATING TEMPERATURES
- IMPROVED COOLING IS EXPENSIVE IN MASS AND POWER
- IMPROVED DETECTOR PERFORMANCE IS EXPENSIVE IN UP FRONT DEVELOPMENT COSTS

SAFIRE MEASUREMENT OBJECTIVES

- Conduct global-scale, simultaneous, vertical profile measurements of temperature and key O_y, HO_y, NO_y, ClO_y, and BrO_y constituents, including the following:



- Conduct measurements (e.g. T, O₃, CH₄, and H₂O) that can be used to derive and study dynamical quantities such as geopotential height, potential vorticity, winds, and Eliassen Palm flux
- Employ a 3 km IFOV in the far IR and 1.5 km in the mid IR
- Provide scan mode flexibility to enhance science return
 - Chemistry mode, 10-110 km vertical scan, 1.5 km sampling interval, 5° of latitude
 - Polar chemistry mode, 10-106 km, 3 km, 2.5°
 - Dynamics mode, 10-100 km, 0.75 km, 1.25°
 - Thermospheric mode, 84-180 km, 3 km, 5°

SAFIRE Experiment Measurement Objectives

Parameters Measured ¹	Spectral Range (cm ⁻¹)	Alt. Range (km)	IFOV ² (km)	Horizontal Resolution ³		Temporal Resolution (sec.) ⁴	Lat. Cov. (deg.)	Estimated Precision ⁵	
				Lat. (deg.)	Long. (deg.)			% (1σ)	Vertical Range (km)
O ₃	82 - 84.4; 926 - 1141	10 - 100	1.5 - 3	1 - 5	25	18 - 72	86°S - 86°N	5	10 - 70
O(³ P)	157 - 159	90 - 180	3	2.5 - 5		36 - 72		15	110-180
OH	82 - 84.4; 117.8 - 119.6	20 - 90	3	2.5 - 5		36 - 72		7	30 - 75
HO ₂	93.8 - 96; 111.0 - 112.6	20 - 75	3	2.5 - 5		36 - 72		7	30 - 60
H ₂ O ₂	93.8 - 96	20 - 50	3	2.5 - 5		36 - 72		7	30 - 35
H ₂ O	157 - 159	10 - 100	3	2.5 - 5		36 - 72		5	20 - 80
HDO	93.8 - 96	10 - 60	3	2.5 - 5		36 - 72		7	20 - 50
CH ₄	1335 - 1365	10 - 65	1.5	1 - 5		18 - 72		7	15 - 55
NO ₂	1560 - 1630	15 - 60	1.5	1 - 5		18 - 72		5	20 - 55
HNO ₃	850 - 920	10 - 45	1.5	1 - 5		18 - 72		7	15 - 40
N ₂ O ₅	310 - 390; 1230 - 1260	10 - 45	1.5 - 3	1 - 5		18 - 72		10	20 - 40
HCl	82 - 84.4	10 - 65	3	2.5 - 5		36 - 72		5	25 - 55
HOCl	98.5 - 100; 117.8-119.6	20 - 45	3	2.5 - 5		36 - 72		7	35 - 40
IBr	98.5 - 100	15 - 40	3	2.5 - 5		36 - 72		10	25 - 35
HF	82 - 84.4	40 - 60	3	2.5 - 5		36 - 72		15	40 - 60
Temp.	630 - 670; 580 - 760	10 - 110	1.5	1 - 5		18 - 72		<0.5K	16 - 65
Pressure	630 - 670; 580 - 760	10 - 110	1.5	1 - 5		18 - 72		<2	16 - 70
O ₂	82 - 120	10 - 80	3	1 - 5		36 - 72		<2	10 - 65
O ₃ (v ₂)	82-84.4	20-50	↓	2.5-5	↓	↓	↓	10*	20-40
O ₃ (v _{1,3})	82-84.4	20-35	↓	2.5-5	↓	↓	↓	15*	20-30
¹⁸ O ₃	82-84.4	20-40	↓	2.5-5	↓	↓	↓	15*	20-35

SAFIRE Experiment Measurement Objectives (Con't)

Parameters Measured ¹	Spectral Range (cm ⁻¹)	Alt. Range (km)	IFOV ² (km)	Horizontal Resolution ³		Temporal Resolution (sec.) ⁴	Lat. Cov. (deg.)	Estimated Precision ⁵	
				Lat. (deg.)	Long. (deg.)			% (1σ)	Vertical Range (km)
O ¹⁸ O	82-84.4	20-35	3	2.5-5	25	36-72	86°S - 86°N	15*	20-30
¹⁷ O	117.8-119.8	20-40	↓	↓	↓	↓	↓	15*	20-35
O ¹⁷ O	82-84.4	20-35	↓	↓	↓	↓	↓	40*	20-30
H ₂ ¹⁸ O	93.8-96, 117.8-119.8	20-60	↓	↓	↓	↓	↓	10*	20-50
H ₂ ¹⁷ O	99.2-101.4, 117.8-119.8	20-50	↓	↓	↓	↓	↓	10*	20-40
HCN	82-84	25-35	↓	↓	↓	↓	↓	35*	25-30
N ₂ O	1230-1260	20-40	1.5	1-5	↓	↓	↓	15*	20-35

*These are estimated precisions based on spectral features and absorption strengths. Retrieval simulations have not been performed.

¹Does not include derived quantities such as winds, potential vorticity, and others.

²Vertical resolution is estimated to be 4 km.

³ Latitudinal resolution is determined by vertical profile skew or ground-track motion during the measurement time. Longitudinal resolution is determined by the orbital spacing. The horizontal FOV width is $\sim 0.1^\circ$.

⁴Observations are made continuously with a vertical profile scan time of 72 sec in the chemistry and thermospheric modes, 36 sec in the polar chemistry mode, and 18 sec in the dynamics mode.

⁵Precision is the 1 σ uncertainty determined from simulation set of 5 retrievals, except for HDO which is for a single retrieval only.

SAFIRE INSTRUMENT PARAMETERS

- **Mass** 304 kg
- **Power (watts)** Average--304, Peak--350, Standby--175
- **Data Rate** 9 mbs (FTS), 9 kbs (Radiometer)
- **Envelope** 1.5m(L) x 1.5m(W) x 1.5m(H)
- **Limb View Direction**

Elevation	14° to 27° depression angle
Azimuth	+ 10° Forward - 170° Aft

SAFIRE MID-IR DETECTOR REQUIREMENTS

CHANNEL	FREQUENCY (cm ⁻¹)	DYNAMIC RANGE (E+03)	D* REQUIRED (E+10 cm (Hz/W) ^{1/2})
1	630-670	7	1.4
2	580-760	28	1.5
3	850-920	7	1.5
4	1335-1365	1	1.4
5	1560-1630	1	1.4
6	926-1141	15	1.6
7	1230-1260	1	1.5

CONFIGURATION: 15 x 7 Array
ELEMENT SIZE: 0.2 x 0.3 mm

SAFIRE FAR-IR REQUIREMENTS

CHANNEL	FREQUENCY (cm ⁻¹)	NO. OF DETECTORS	TYPE	NEP (W Hz ^{-1/2}) x E-15
1	82-85	8	Ge:Ga	1
2	94-96	8	Ge:Ga	1
3	98-100	8	Ge:Ga	1
4	111-113	8	Ge:Ga	1
5	118-120	8	Ge:Ga	1
6A	157-160	4	Ge:Ga	1
6B	310-390	4	Ge:Be	10

CONFIGURATION: (3) 2 x 8 ARRAYS
ELECTRONICS: TIA-JFET 10 kHz BANDWIDTH
BLIP-LIMITED PERFORMANCE (10¹⁰ ph/sec-typical)
DETECTORS TO BE PROVIDED BY FRANCE